



SURGERY OF THORACIC DISC HERNIATION: A SYSTEMATIC REVIEW OF ENGLISH-LANGUAGE LITERATURE

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The presented review of scientific publications from the Medline (PubMed) and Scopus databases considers modern surgical approaches used to remove intervertebral hernias in the thoracic spine. The advantages and disadvantages of anterior and posterior approaches are analyzed. It has been revealed that the anterior approaches, providing a good opportunity to remove a hernia, are associated with the risk of serious complications, including pulmonary ones, and often lead to the formation of a post-thoracotomy pain syndrome. Mini-thoracotomy and percutaneous thoracoscopy, although less invasive, do not exclude the development of complications inherent in conventional thoracotomy. Modern posterior approaches are less traumatic and allow, with minimal contact with the spinal cord, to successfully remove not only soft tissue, but also ossified disc herniation. The choice of the optimal method of discectomy remains an unsolved problem and depends on practical skills, experience and preferences of the surgeon. For an objective and reliable assessment of the efficiency of surgical technologies and the determination of optimal indications for each of them, a prospective multicenter study is necessary.

Key Words: thoracic spine, intervertebral hernia, surgical approaches.

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Thoracic herniated discs account for 0.25 to 0.75 % of all disc herniations [1]. The annual incidence rate of thoracic disc herniation is about 1 case per 1,000,000 population, with almost 75 % of symptomatic disc herniations being located in the lower thoracic spine (at T8–T9 to T11–T12), mainly at the T11–T12 level [1, 2]. Although this pathology is rare, various aspects of its surgical treatment and, primarily, development of effective and safe surgical approaches are a challenge that causes many discussions among spine surgeons.

The purpose of this study is to evaluate the efficacy of modern techniques for surgical treatment of thoracic disc herniations.

Material and Methods

The search for scientific publications was carried out in the Medline (PubMed) and Scopus databases using the following keywords: “thoracic disc”, “herniation”, “surgery”, and “approach”. The publication period was limited to 01.01.2008 through 12.31.2018, which was associated with the purpose to

reflect the current state of the problem, although some publications included outcomes of interventions performed before 2008. A total of 898 English language articles published in peer-reviewed journals were selected.

Because of a small number of randomized controlled trials, both retrospective and prospective studies were included in the review. The publications were supposed to reflect surgical treatment outcomes in patients with thoracic disc herniations and provide the data of preoperative and postoperative examinations. We selected articles containing clinical information (pain, disability, and/or quality of life assessment), individual characteristics of patients (gender, age, etc.), anatomical features (level and number of affected discs), and history of surgical interventions (surgery type, surgical technique, spinal segment fixation, fixation method, surgery duration, blood loss, and complications).

The exclusion criteria were as follows: the number of cases is 10 or less (with allowance for a rare occurrence of this pathology and a small number of these operations), traumatic genesis of hernia-

tion, and combination of herniation with scoliosis. Also, we excluded articles not focused on treatment of thoracic disc herniations, anatomical studies, and animal-based studies.

Full texts of 119 potentially appropriate publications were analyzed; 23 publications were selected for this review as completely matching the inclusion criteria (Fig.).

Results and Discussion

Indications for surgery. There were no significant differences among publications in the indications for removal of symptomatic thoracic disc herniations. The main indications for surgery were myelopathy and radiculopathy whose discogenic origin was confirmed by MRI and CT findings. Isolated radiculopathy was an indication for surgery in the presence of pronounced chronic pain syndrome tolerant to conservative therapy, but the optimal timing for surgery was not defined [3–5].

Surgical options and choice of surgical approach. The choice of an optimal surgical procedure is a difficult task for the

surgeon. The requirements for a surgical approach are defined and clearly formulated: the approach must ensure removal of the herniated disc and, which is extremely important, minimize contact with the spinal cord [6–9]. In the studies, the goal of surgery was decompression of the spinal cord and, in the case of isolated radiculopathy, of a compromised spinal root. When choosing the optimal technique, all authors assessed the location of herniation relative to the midline (medial, lateral), its size (small, medium, large, giant), and its morphological features (soft or ossified disc herniation).

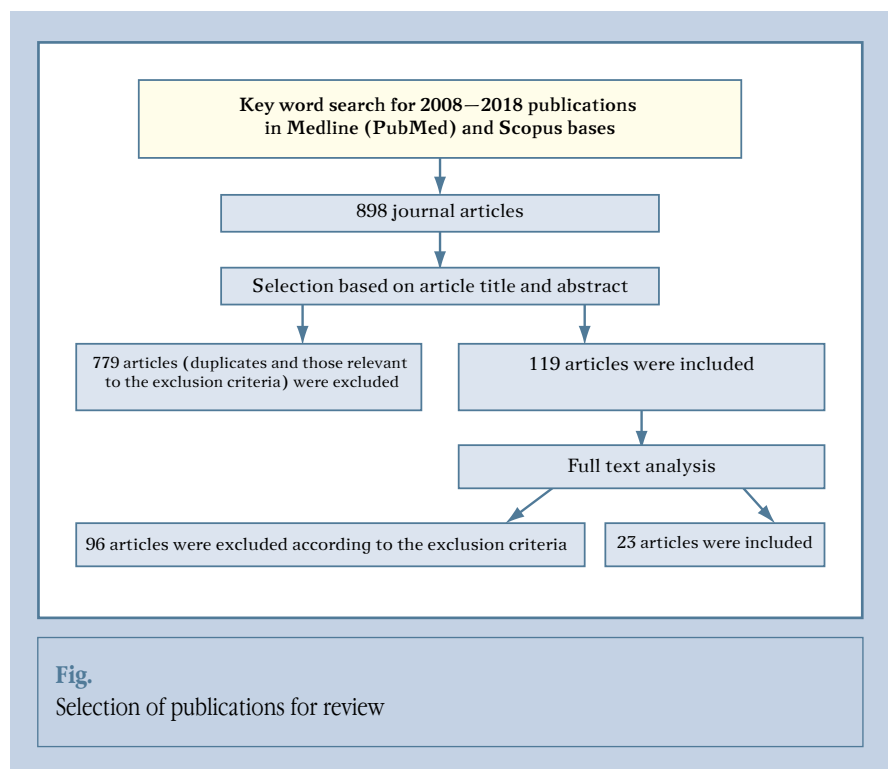
To date, a variety of techniques for surgical treatment of thoracic disc herniations have been developed; minimally invasive microsurgical and endoscopic techniques are used. To remove disc herniations, the authors of reviewed publications used thoracotomy [6, 10–12], mini-thoracotomy [9, 13, 14], retropleural transthoracic [15] and percutaneous thoracoscopic approaches [4, 5, 16], as well as various posterior surgical approaches [7–9, 12, 17–26]. Thoracotomy provided a good view and control of the surgical area as well as a wide access to the intervertebral disc and anterior dural sac, without sac traction, thereby reducing the risk of conflict with the spinal cord [10, 11]. An open transthoracic approach was preferred for removal of giant, medial, and ossified disc herniations. However, thoracotomy is invasive and associated with the risk of pulmonary complications (hemothorax, pneumothorax, pneumonia, pleurisy, reactive pleural transudation) and, in the case of dural injury (cerebrospinal fluid-pleural fistula), is often accompanied by postoperative intercostal neuralgia and dysesthesia [10–12]. Mini-thoracotomy involving special dilators and microsurgical equipment is less traumatic but does not eliminate the risk of the same complications as in the case of conventional thoracotomy. For example, Roelz et al. [13] reported a case of a cerebrospinal fluid fistula and a case of reactive pleural transudation after 17 mini-thoracotomies. Strom et al. [14] used a tubular mini-approach and reported postoperative intercostal neuralgia in one of 13 operated patients. Arts et al. [9] reported 10 cases of postoperative pneumonia and/or reactive pleural tran-

sudation as well as two cases of dura mater injury associated with removal of 56 herniations via a transthoracic mini-approach; in the postoperative period, two patients experienced neurological deficit worsening. Moran et al. [15] removed thoracic disc herniations via a transthoracic retropleural approach, considering avoidance of pleural cavity drainage as an advantage of the approach. The pleura was injured during access in 5 of 17 cases, which required pleural drainage in one case and led to pleural CSF hygroma in another case; two patients experienced a temporary decline in neurological status; one patient developed severe pneumonia on the side contralateral to the intervention.

A percutaneous thoracoscopic (endoscopic) approach is less invasive compared to open thoracotomy [4, 5, 16]. In the publications included in the study, thoracoscopic discectomy was used both for soft and for ossified and midline disc herniations. However, these minimally invasive techniques with minimal soft tissue injury were not free of complications typical of other surgical approaches. In cases reported by Wait et al. [16], blood loss was 311 mL during thoracoscopic discectomy and 1,440 mL during thoracotomy, on average.

In this case, dural injury during thoracoscopic surgery occurred in 1.7 % of cases; in the postoperative period, intercostal neuralgia developed in 5.8 % of patients; pleural transudation was observed in 5.0 % of cases. According to Brauge et al. [4], pleural CSF hygroma developed in 5 of 53 cases after thoracoscopy. According to Quint et al. [5], out of 167 endoscopically operated patients, postoperative intercostal neuralgia developed in 5.4 % of cases; pulmonary complications, including pneumothorax and pleural transudation, developed in 3.6 % of the operated patients; the dura mater was intraoperatively injured in 1.2 % of cases. The authors believe that thoracoscopic operations for large-sized ossified disc herniations are associated with a high risk of complications and are preferable for removal of soft and lateral disc herniations, while according to Brauge et al. [4], thoracoscopic surgery is a suitable surgical treatment for giant and ossified disc herniations. There is no consensus on limitations of the thoracoscopic technique for herniations with different localization and structure.

Posterior surgical approaches used for removal of thoracic disc herniations have a number of technical options: transfacet, transpedicular, and transforaminal. They



are not associated with post-thoracotomy syndrome and less invasive compared to thoracotomy. Resection of the facet joints, vertebral pedicles, transverse processes, and medial ribs, which is used in various posterior approaches, provides access to the posterolateral intervertebral disc away from the dural sac, thereby minimizing contact with the spinal cord. There is no consensus on optimal indications for the use of posterior approaches in thoracic spine discectomy. Arts et al. [9], Kapoor et al. [12], and Yuce et al. [18] used a posterior approach to remove paramedian non-ossified disc herniations, while other authors [7, 8, 20–23, 25] used a posterior approach to remove median ossified disc herniations as well. Pei et al. [8] started removal of ossified median disc herniations with resection of the underlying bone tissue; as a result, the outer part of the herniated disc, adjacent to the dura mater, became thinned and was easily, like an eggshell, removed. Smith et al. [24] and Choi et al. [26] used a posterior foraminoscopic approach to remove lateral soft disc herniations.

In some cases, depending on the type and features of the decompression stage, the authors of studies performed fixation of operated segments. For this purpose, instrumentation for external and internal fixation, cages, and allograft bones were used; however, the publications lacked clear indications for the use of stabilization. In the case of partial vertebral body resection that usually accompanies removal of ossified disc herniations, the segment was stabilized if the size of a removed endplate was greater than 25 % [9] or, according to Brauge et al. [4], 50 % of its area.

Surgical treatment outcomes (Table 1). An attempt to obtain evidence-based comparable statistical data on the efficacy of different surgical options has failed. Publications differ in the completeness of clinical data description, postoperative follow-up duration (from 6 months to 4 years or more), and scales used for assessing the patients' condition; in addition, interpretation of the scales is different. The reviewed publications do not provide differentiated information about surgical treatment outcomes depending on the location and structure of the herniated disc as well as fixation of the vertebral segments. A similar

problem of incomparability of study results in individual publications and impossibility of their generalization was encountered by Steiger et al. [27] in a systematic analysis of the scientific literature on degenerative spondylolisthesis: an evaluation of the methodological quality of publications and the risk of their bias using the Downs and Black checklist gave a low score to many studies selected for this review. It should be noted that we reviewed mainly retrospective studies that included small numbers of patients, which is obviously due to a relatively low prevalence of this pathology. Given these facts, the treatment outcome statistics presented in Table 1 can not be used for evidence-based comparative analysis. However, these results may provide a general idea of the efficacy of various surgical interventions and indications for their use.

In the reviewed publications, surgical outcomes are allocated into three groups: improvement, no changes, and deterioration. Myelopathy is not always reversible, and restoration of the spinal cord functions after decompression depends not always and not only on the quality of surgery but also on reversibility of changes in the spinal cord tissue. Therefore, removal of a herniated disc is aimed at restoring the spinal cord functions and preventing their further deterioration [3]. Thus, the surgical outcome may be evaluated as favorable in the case of successful removal of a herniated disc with complete spinal cord decompression and neurological status stabilization.

Transthoracic approaches provide the best conditions for removal of central calcified herniations, but their use is associated with the development of complications such as intercostal neuralgia, pneumonia, reactive pleural transudation, empyema, and cerebrospinal fluid-pleural fistula [28]. Ayhan et al. [10], Zhao et al. [11], Kapoor et al. [12], and Quraishi et al. [6] performed discectomy through transthoracic approaches in the case of medial/paramedial ossified disc herniations. A publication by Ayhan et al. [10] reports successful removal of medial ossified disc herniations and the favorable outcomes achieved in most cases: only two patients developed deterioration after surgery. In this case, six of 27 operated patients developed severe complications: tension pneumothorax (2 cases), deep vein

thrombosis (1 case), and complications related to technical defects of instrumentation (3 cases). Zhao et al. [11] reported 15 patients with discogenic myelopathy who underwent successful removal of giant (more than 40 % of the spinal canal diameter) ossified disc herniations through the transthoracic approach. Partial regression of neurological symptoms occurred in nine cases; there were no changes in three cases, but these patients were satisfied with the surgical outcomes because they had no worsening of the neurological deficit. None of the operated patients had complications. Kapoor et al. [12] compared the opportunities and outcomes of thoracic discectomy performed via different surgical approaches and concluded that the transthoracic approach is preferable for removal of giant herniations. After removal of these herniations through the thoracotomy approach, favorable surgical outcomes were achieved in 19 of 22 cases. However, the approach is invasive and associated with the risk of complications. Five patients had intercostal neuralgia, one patient had reactive pleural effusion, one patient had a cerebrospinal fluid-pleural fistula, and one patient had delayed lower paraparesis due to incomplete removal of herniation. However, Kapoor et al. [12] note that the risk of these specific complications is known and expected and, therefore, can be controlled. Despite the drawbacks of the anterior approach, the opinion that thoracotomy is the most appropriate approach for removal of giant thoracic disc herniations is also supported by the authors of earlier studies not included in this analysis [2, 29].

Our study includes the results of using minimally invasive anterior approaches for removal of thoracic disc herniations, the purpose of which is to reduce morbidity of operations compared to that of conventional thoracotomy [9, 13, 14]. Roelz et al. [13] removed 17 giant, including 14 ossified, thoracic disc herniations via a mini-approach using special retractors and microsurgical equipment; there were 6 herniations with intradural extension. In all cases, herniated discs were successfully removed. In the postoperative period, there were two cases of transient worsening of paraparesis and two cases of transient paraplegia, followed by regres-

Table 1

How the authors of publication assessed treatment outcomes in patients operated on using various surgical approaches

| Authors | Number of patients, n | Scale | Surgical treatment outcome, n (%) | | |
|---|--------------------------|-----------------------------|-----------------------------------|------------|---------------|
| | | | Improvement | No changes | Deterioration |
| Thoracotomy | | | | | |
| Auhan et al. [10] | 27 | ASIA | 12 | 13 | 2 |
| Zhao et al. [11] | 15 | JOA | 13 | 2 | 0 |
| Kapoor et al. [12]** | 22 | Frankel | 11 | 8 | 3 |
| Quraishi et al. [6] | 13 | Frankel | 10 | 3 | 0 |
| TOTAL | 77 | | 46 (60) | 26 (34) | 5 (6) |
| Mini-thoracotomy | | | | | |
| Roelz et al. [13] | 17 | JOA | 14 | 1 | 2 |
| Strom et al. [14] | 13 | ASIA, Nurik | Non-comparable data | | |
| Arts et al. [9] | 56 | ASIA | 28 | 25 | 3 |
| TOTAL | 73* | | 42 (58) | 26 (36) | 5 (6) |
| Retropleural transthoracic approach | | | | | |
| Moran et al. [15] | 17 | Frankel, 36-ISF, ODI | 13 (76) | 3 (18) | 1 (6) |
| Percutaneous thoracoscopy | | | | | |
| Brauge et al. [4] | 53 | Frankel | 44 | 7 | 2 |
| Wait et al. [16] | 68 | Frankel, VAS | 50 | 18 | 0 |
| Quint et al. [5] | 167 | VAS | Non-comparable data | | |
| TOTAL | 121* | | 94 (77) | 25 (21) | 2 (2) |
| Posterior and posterolateral approaches | | | | | |
| Khoo et al. [17] | 13 | Frankel | 9 | 4 | 0 |
| Kapoor et al. [12]** | 11 | Frankel | 4 | 7 | 0 |
| Yuce et al. [18] | 23 | VAS, ODI | Non-comparable data | | |
| Arts et al. [9] | 44 | ASIA | Non-comparable data | | |
| Bransford et al. [7] | 18 | ASIA, Nurik, Motor Score | Non-comparable data | | |
| Carr et al. [19] | 51 | ASIA | 19 | 32 | 0 |
| Chi et al. [20] | 11 | Prolo | 7 | 4 | 0 |
| Coppes et al. [21] | 13 | Frankel | 6 | 7 | 0 |
| Pei et al. [8] | 26 | ASIA | 24 | 2 | 0 |
| Yang et al. [22] | 25 | JOA | 23 | 2 | 0 |
| Sivakumaran et al. [23] | 24 | Frankel | 13 | 11 | 0 |
| Smith et al. [24] | 16 | McNab | 13 | 1 | 2 |
| Zhuang et al. [25] | 27/24 | Frankel/JOA | 26/23 | 1/1 | 0/0 |
| Choi et al. [26] | 14 | VAS, ODI | 14 | 0 | 0 |
| TOTAL | 231* | | 158 (68) | 71 (31) | 2 (1) |

*Data non-comparable within studies are not included in the TOTAL entity;

**patients were operated on through anterior and posterior approaches.

sion within 3–6 months. Finally, favorable surgical outcomes were achieved in 15 cases; the condition deteriorated in two cases. The use of the mini-approach did not prevent the development of thoracotomy syndrome: in the postoperative period, intercostal neuralgia developed in 5 out of 17 cases. In addition, one patient developed pleural effusion, and another had a CSF-pleural fistula. Strom et al. [14]

who performed 13 discectomies through a mini-approach using a tubular retractor noted intercostal neuralgia in one case only, without any other complications. Arts et al. [9] reported 10 cases of pneumonia, 10 cases of cerebrospinal fluid leak, and 3 cases of neurological deficit worsening after 56 mini-thoracotomies. Totally, favorable surgical outcomes were achieved in 68 out of 73 cases. According to the presented

results, mini-thoracotomy provided successful removal of giant ossified thoracic disc herniations but did not rule out the risk of post-thoracotomy syndrome. This opinion is shared by the authors of earlier studies [2, 30].

In recent years, endoscopic techniques have been increasingly used in surgery. However, the theoretical advantages of these techniques for intervertebral disc

surgery have not been convincingly confirmed in practice.

In addition, mastering of the endoscopic technique requires prolonged and advanced training and regular practicing; because thoracic disc herniation is a rare pathology, implementation of endoscopic discectomy in medical institutions is unrealistic.

According to Quint et al. [5], the overall rate of intra- and postoperative complications after thoracoscopic discectomy for discogenic myelopathy is 15.6 % of cases, including intercostal neuralgia (5.4 % of cases), pulmonary complications (3.6 % of cases), extremity paresis (1.2 % of cases), hypesthesia (0.6 % of cases), and dural injuries, including cerebrospinal fluid leak, (1.6 % of cases). Assessment of the long-term surgical outcomes at 2 years revealed good and excellent recovery of motion in 52 of 61 examined patients; two patients had no changes; and five patients developed weakness in the lower extremities. The authors compared thoracoscopy and thoracotomy by the number of postoperative complications and found a significantly lower rate of intercostal neuralgia in the case of thoracoscopy (5.4 % vs. 23.1 %), almost half the hospital stay, and less blood loss. However, there was no difference in the rate of pulmonary and cardiovascular complications and intraoperative dural injury. According to Wait et al. [16], the rate of intercostal neuralgia was 5.8 % after thoracoscopic surgery and 23.1 % after thoracotomy. The authors did not reveal any difference between thoracoscopy and thoracotomy in the rate of pulmonary and cardiovascular disorders. Brauge et al. [4] reported the results of thoracoscopic removal of giant ossified thoracic disc herniations in 53 patients. In the postoperative period, eight patients experienced neurological deficit worsening, which regressed subsequently. After surgery, two patients developed new neurological disorders, including one case of paraplegia. There were five cases of intraoperative injury to the dura mater, which led to the development of intrapleural hygromas; one patient developed pleural effusion, which confirmed that not only the open technique but also

the endoscopic percutaneous technique is suitable for these operations. In the long-term period, 44 patients had improvement (Frankel scale); 7 patients had no changes; 2 patients experienced worsening. The study results suggest that thoracoscopic discectomy at the thoracic level may be a potential alternative to open transthoracic surgery.

The authors of most publications used posterior approaches to remove central and paracentral, soft and ossified, disc herniations. Minimally invasive transforaminal approaches enabled removal of only lateral disc herniations located near the intervertebral foramen [24, 26]. Minimally invasive thoracic discectomy provided positive outcomes in 13 of 16 cases in a study by Smith et al. [24] and in all 14 patients, in the absence of complications, in a study by Choi et al. [26]. Posterior and posterolateral approaches are markedly different from anterior ones by a lower rate and severity of complications. According to Kapoor et al. [12], posterolateral costotransversectomy is as much effective as the transthoracic approach in removal of thoracic disc herniations and has a better complication profile than the latter.

The authors of publications devoted to the posterior approach believe that advantages of the approach are related not only to a lower rate of complications but also to better control of the epidural space, its venous vessels, and dura mater condition [7, 19, 22]. A diversity of posterior approaches enhances their application and enables removal of not only soft lateral but also medial ossified disc herniations [7, 8, 20, 21, 22, 25]. Coppes et al. [21] removed 13 herniated discs through a posterior transdural approach and achieved favorable outcomes in all cases. Complications included CSF leak, transient radicular pain (1 case), and superficial wound infection (1 case). Yang et al. [22] removed 25 medial ossified disc herniations using the eggshell procedure. In two cases, the dura mater was injured, and a subdural hematoma developed. Persistent postoperative neurological complications associated with posterior approaches were reported only by Smith et al. [24] and Zhuang et al. [25] totally

in three patients, which is quite comparable with the outcomes of operations performed through anterior approaches. Table 2 presents the conclusions made by the authors of the reviewed publications.

Conclusion

The analysis of the literature did not reveal indisputable advantages of any of the surgical approaches used for removal of thoracic disc herniations. Both anterior and posterior approaches have been successfully used by different authors to remove herniations of different localization and different morphological structure.

However, in contrast to posterior approaches, anterior approaches including minimally invasive ones are associated with a risk of serious pulmonary complications. According to some authors, anterior approaches provide greater opportunities for removal of giant ossified disc herniations. Thoracoscopic surgery is less traumatic and, in certain cases, can be an alternative to traditional surgical interventions performed through an open anterior approach. Removal of a thoracic herniated disc through posterior and posterolateral approaches is more versatile, less traumatic, and not associated with the risk of severe pulmonary complications and post-thoracotomy syndrome. The surgeon's choice of a surgical technique is largely based on personal preferences, practical skills, and experience in surgical techniques.

The reviewed publications report mainly small series of patients, and the absence of poor outcomes in many of them may be explained by an insufficient number of cases and does not cause questions. However, a small total number of poor outcomes in all groups lead to the conclusion that a prospective multicenter study is required to objectively and reliably assess the efficacy of surgical techniques and define optimal indications for each of them.

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The authors declare no conflict of interest.*

Table 2

Conclusions made by authors of the reviewed publications

| Authors included in the review | Article title | Number of patients, n | Authors' conclusions |
|--------------------------------|---|-----------------------|---|
| Ayhan et al. [10] | Thoracic disc herniations presenting with myelopathy a 5-year institutional experience | 27 | Thoracotomy for treatment of centrally located thoracic disc herniations is associated with improvement in or stabilization of myelopathic symptoms in the majority of patients with an acceptable rate of complications. Most patients with weakness improved in strength (75 %), no patients with normal strength developed new weakness (100 %), and only 2 patients had new weakness noted postoperatively (7.4 %) |
| Khoo et al. [17] | Minimally invasive extracavitary approach for thoracic discectomy and interbody fusion: 1-year clinical and radiographic outcomes in patients compared with a cohort of traditional anterior transthoracic approaches | 13 | Compared with transthoracic procedures, MIECTDF effectively decompressed the spinal canal, yielding identical 1-year radiographic and clinical outcomes to those seen in controls, while producing superior clinical scores in the interim |
| Moran et al. [15] | Mini-open retropleural transthoracic approach for the treatment of giant thoracic disc herniation | 17 | Mini-open thoracotomy and retropleural approach coupled with a limited bony resection surrounding the giant disc, without corpectomy or instrumentation, represents an effective, safe, and appropriate surgical treatment for the resection of giant thoracic discs |
| Quraishi et al. [6] | Calcified giant thoracic disc herniations: considerations and treatment strategies | 13 | Calcified GHTD remain a surgical challenge. Anterior decompression through a thoracotomy approach, and varying degrees of vertebral resection with or without reconstruction allowed us to safely remove the calcified fragment |
| Roelz et al. [13] | Giant central thoracic disc herniations: surgical outcome in 17 consecutive patients treated by mini-thoracotomy | 17 | The obvious advantages of thoracotomy – the optimal anterior exposure and the applicability of common microsurgical skills – outweigh the potential benefits of less invasive approaches (e.g. thoracoscopy or dorso-lateral approaches) |
| Strom et al. [14] | Technical modifications and decision-making to reduce morbidity in thoracic disc surgery: An institutional experience and treatment algorithm | 64 | Several strategies may reduce morbidity from thoracic disc surgery: careful approach selection, preoperative level marking, use a tubular retractor with thoroscopic guidance, rib resection at the mini-thoracotomy site, routine chest tube placement for anterior operations, and routine lumbar drain insertion in the event of a dural tear. Prospective comparative studies are needed to assess the efficacy of these techniques |
| Zhao et al. [11] | Transthoracic approach for the treatment of calcified giant herniated thoracic discs | 15 | Transthoracic decompression combined with reconstruction, fusion, and fixation is an effective method for the treatment and is associated with a low rate of complications and neurological impairment |
| Yuce et al. [18] | Midterm outcome of thoracic disc herniations that were treated by microdiscectomy with bilateral decompression via unilateral approach | 23 | Microdiscectomy with bilateral decompression via a unilateral approach (BDUA) for thoracic disc herniations resulted in a significant reduction of symptoms and disability |

Continuation of Table 2

| | | | |
|-------------------------|--|----|--|
| Bransford et al. [7] | Early experience treating thoracic disc herniations using a modified transfacet pedicle-sparing decompression and fusion | 18 | A modified transfacet pedicle-sparing approach combined with fusion offers a safe means of achieving concurrent decompression and segmental stabilization and is an option for certain subtypes of TDH. Although 6 patients required additional surgery for postoperative complications, all patients experienced improvement relative to their preoperative status |
| Carr et al. [19] | Management of thoracic disc herniations via posterior unilateral modified transfacet pedicle-sparing decompression with segmental instrumentation and interbody fusion | 51 | The posterior unilateral modified transfacet pedicle-sparing decompression and instrumented fusion approach to the thoracic spine is a safe and reproducible procedure for the treatment of TDHs |
| Chi et al. [20] | The mini-open transpedicular thoracic discectomy: surgical technique and assessment | 11 | The mini-open transpedicular discectomy for thoracic disc herniations results in better modified Prolo scores at early postoperative intervals and less blood loss during surgery than open posterolateral discectomy |
| Coppes et al. [21] | Posterior transdural discectomy: a new approach for the removal of a central thoracic disc herniation | 13 | Although the present series is still small, the posterior transdural approach seems an appealing and promising procedure for the removal of a central thoracic disc herniation |
| Pei et al. [8] | Circumferential decompression via a modified costotransversectomy approach for the treatment of single level hard herniated disc between T10–L1 | 26 | This procedure achieves sufficient direct visualization for circumferential decompression of the spinal cord via a posterior midline covered costotransversectomy approach with friendly bleeding control and without muscle sacrifice. It is a reasonable alternative treatment option for thoracic myelopathy caused by a single level hard thoracic herniated disc between T10–L1 |
| Yang et al. [22] | Modified eggshell procedure via posterior approach for sclerosing thoracic disc herniation: a preliminary study | 25 | Modified eggshell procedure via the posterior approach is a safe and effective surgical method when performed to treat sclerosing thoracic disc herniation in the clinical practice |
| Sivakumaran et al. [23] | Posterolateral-only approach to thoracic disc herniation. | 24 | TDH including large central calcified discs can be safely removed through posterior transfacet or transpedicular approaches with reduced morbidity in comparison with more invasive anterior approaches. Careful microsurgical technique and use of specialized instruments are important for successful excision of TDH from a posterior approach |
| Smith et al. [24] | Minimally invasive thoracic microendoscopic discectomy: surgical technique and case series | 16 | Thoracic microendoscopic discectomy is a safe and effective minimally invasive posterolateral approach for the treatment of thoracic disc herniations that lacks the morbidity associated with traditional approaches |
| Zhuang et al. [25] | Surgical treatment for central calcified thoracic disk herniation | 27 | The results suggest that the posterior approach using a special L-shaped osteotome is feasible. No major complications occurred while achieving adequate decompression for central calcified TDH |

End of Table 2

| | | | |
|--------------------|--|-----|---|
| Brauge et al. [4] | Management of giant thoracic disc herniation by thoracoscopic approach: experience of 53 cases | 53 | Preserving neurological function is the main goal of this functional surgery. A subtotal or incomplete resection must be considered if the risk of neurological worsening is high and if spinal decompression has been achieved. Our results suggest that the thoracoscopic approach is a valid therapeutic option in giant symptomatic TDHs |
| Choi et al. [26] | Percutaneous endoscopic thoracic discectomy; transforaminal approach | 14 | This PETD technique is applicable in limited cases of symptomatic soft TDH. And it is a safe and effective method that provides a direct route to the lesion under local anesthesia |
| Quint et al. [5] | Thoracoscopic treatment for single level symptomatic thoracic disc herniation: a prospective followed cohort study in a group of 167 consecutive cases | 167 | Thoracoscopic microdiscectomy for single level symptomatic disc herniation is a highly effective and reliable technique, it can be performed safely with low complication rate |
| Wait et al. [16] | Thoracoscopic resection of symptomatic herniated thoracic discs. Clinical results in 121 patients | 121 | Thoracoscopic HTD resection subjected patients to shorter hospital stays, shorter chest tube duration, less blood loss, and a less risk of intercostal neuralgia than in an unmatched thoracotomy cohort |
| Arts et al. [9] | Anterior or posterior approach of thoracic disc herniation? A comparative cohort of mini-transthoracic versus transpedicular discectomies | 100 | The approach is dependent on the location, the magnitude, and the consistency of the herniated thoracic disc. Medially located large calcified herniated discs should be operated through an anterolateral approach, whereas noncalcified or lateral herniated discs can be treated from a posterior approach as well. For optimal treatment of this rare entity, the treatment should be performed in selected centers |
| Kapoor et al. [12] | Giant thoracic discs: treatment, outcome, and follow-up of 33 patients in a single centre | 33 | Surgical approach should be chosen according to individual disc characteristics. Significant approach-related complications are to be anticipated in patients undergoing thoracotomies, most of them being manageable. The authors support costotransversectomy, preferably in paracentral discs with maller percentage canal stenosis as they offer only a limited view, but offer a better complication profile compared to thoracotomy |

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